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LOAD FREQUENCY CONTROL IN TWO AREA POWER SYSTEM USING ANFIS

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ABSTRACT

The load-frequency control (LFC) is used to restore the balance between load and generation in each control area by means of speed control. The main goal of LFC is to minimize the transient deviations and steady state error to zero in advance. This paper investigated LFC using proportional integral (PI) Controller and Adaptive Neuro Fuzzy Inference System (ANFIS) for two area system. The results of the two controllers are compared using MATLAB/Simu link software package. Comparison results of conventional PI controller and Adaptive Neuro Fuzzy inference System are presented.

KEYWORDS: Load Frequency Control, Adaptive Neuro Fuzzy Inference System (ANFIS), PI Controller

INTRODUCTION

Nowadays, electricity generation is very important because of its increasing necessity. The dynamic behavior of the system depends on disturbances and on changes in the operating point. The quality of the generated electricity in power stations is depending on the system output, it has to be of constant frequency and should maintain the scheduled power. Therefore, Load Frequency Control (LFC) is very important for power system in order to supply reliable and quality electric power. The conventional controllers such as PI, PID can give control action for one particular operating condition, where as in real situation the parameters change from time to time. So it is difficult to arrange the required gains to achieve zero frequency deviation. Hence there is a necessity to provide automatic correction. However research is going on and several methods are developed to overcome this difficulty.

A number of control techniques have been employed in the design of load frequency controllers in order to achieve better dynamic performance. Comparing the various types of load frequency controllers, the most common and widely employed is the conventional proportional (PI) controller. Conventional controller is simple for implementation but gives large frequency deviation. Most of state feedback controllers based on linear optimal control theory have been proposed to achieve better performance. Fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. So to keep the system performance near to its optimum it is desirable to track the operating conditions and use updated parameters to compute the control. Adaptive controllers with self adjusting gains settings have been proposed for LFC to achieve the function compared to PI Controller. As we know that Northern grid failure was due to this load frequency control problem. This is due to the over drawing of power from grid apart from its generation. It resulted to a black out in nearly the entire Northern region covering all the eight states.This was due to the improper control action by the conventional controllers and in spite of the warnings issued, some states were continually drawing excess power. Therefore, an adaptive control system is required to detect the load changes and stabilize the frequency deviation. In this paper an automatic control action is provided through the Adaptive Neuro Fuzzy Inference System (ANFIS) technology. A comparison of the proposed controller is made with the conventional controller and results are presented. The settling time, peak overshoot and frequency deviations are taken as performance indices. The proposed Adaptive Neuro Fuzzy Inference System trains the parameters of the fuzzy logic controller and improves the system performance.

TWO AREA POWER SYSTEM

Modern day power systems are divided into various areas. For example in our India, there are five regional grids, e.g., Easter, Western, Northern, Southern and North-Eastern. Each of these regional areas is generally interconnected to its neighboring areas. The transmission lines which connect an area to its neighboring area are called tie-lines. The Power sharing between two areas is done through these tie-lines. Load frequency control, its name signifies that it regulates the power flow between different areas while keeping the frequency constant.

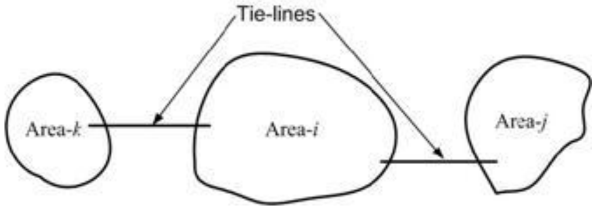

Figure 1: Inter Connected Power System

As we know that the system frequency rises when the load decreases if ΔP_{ref} is kept at zero. Similarly the frequency may decrease if the load increases. However, it is necessary to maintain the frequency constant such that $\Delta f=0$. The power flow between the different tie lines are scheduled - for example, area 'i' may export a pre-specified amount of power to area 'j' while importing another pre-specified amount of power from area 'k' . However it is expected that to fulfill the above duty, area 'i' absorbs its own load change, i.e., increased generation to supply extra load in the area or decreased generation when the load demand in the area has decreased. While doing this area 'i' must however maintain its duty to areas *j* and *k* as far as importing and exporting power is concerned. The block diagram of the interconnected areas is shown in Figure1.

The load frequency control (LFC) has the following objectives:

- Hold the frequency constant (Δf = 0) against any load change. Each area must have the capability to absorb any load change such that frequency does not deviate.
- Each area should maintain the tie-line power flow to its pre-specified value.

The first step in the Load Frequency Control is to form the **area control error (ACE)** that is defined as

$$ACE = (P_{tie} - P_{sc}) + B_f \Delta f = \Delta P_{tie} + B_f \Delta \quad (1)$$

Where P_{tie} and P_{sch} are the **tie-line power** and **scheduled power** through tie-line respectively and the constant B_f is called the **frequency bias constant.**

The change in the reference of the power setting $\Delta P_{ref,\, i}$, of the area- i is then obtained by the feedback of the ACE through an integral controller of the form

$$\Delta P_{ref\ i} = -K_i \int ACE\ dt \quad (2)$$

Where K_i is the integral gain.

The ACE is negative if the net power flow out of an area is low or if the frequency has decreased or both. In this situation the generation must be increased to meet load demand. This can be achieved by increasing $\Delta P_{ref,\, i}$.

This negative sign accounts for this inverse relation between $\Delta P_{ref,\ i}$ and ACE. The tie-line power flow and frequency of each area are monitored in its control center. Once the ACE is computed and $\Delta P_{ref,\ i}$ is obtained from Eq(2), commands are given to various turbine-generator controls to adjust their reference power settings.

A two area power system consists of two single area systems connected through tie-lines. In order to develop any control strategy it is necessary to make a mathematical modeling of that system. It is conveniently assumed that each control area can be represented by equivalent turbine, speed governing system, generator and load. The block diagram for single area power system is shown in Figure2.

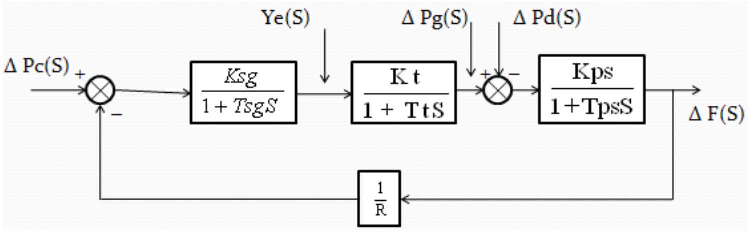

Figure 2: Single Area Power System

In two area power system, each single area has number of generators which are closely coupled together so as to form a coherent group, i.e. all the generators in power system should respond in unison to change in load. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic situation. Initially the changes in load are managed by the speed governing system. But in this system, in order to minimize the frequency deviation again another controller (PI) is used. The PI Controller can give best control action in frequency deviation in one operating condition. In case of large operating range the PI Controllers fail to bring the frequency deviation to minimum. This difficulty is avoided by the Adaptive Neuro Fuzzy Inference System (ANFIS).

The conventional AGC scheme has two control loops. The primary control loop, controls the frequency by self regulating feature of governor, however, frequency deviation is not fully eliminated. And the feedback control loop, has a controller that can eliminate the frequency deviation with the help of conventional proportional integral control action. The main objective of the feedback control is to restore the balance between load and generation in each control area after disturbance, so that the system frequency and the tie-line power flows are maintained at their scheduled values. The block diagram of Load Frequency Control in Two area interconnected power system is shown in Figure3.

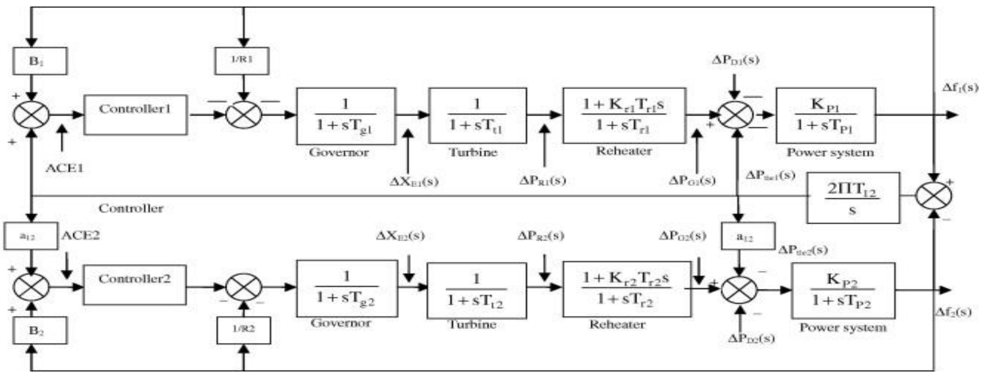

Figure 3: Two-Area Interconnected Power System

PI-CONTROLLER

Among the various types of load frequency controllers, the most commonly employed is the conventional proportional integral (PI) controller. Conventional controller is simple for implementation but takes more time and gives

large frequency deviation. In a single-area case, ACE is the change in frequency. The steady state error in frequency will become zero (i.e., $\Delta f_{ss} = 0$) when ACE is used in an integral-control loop. In a two-area case, ACE is the linear combination of the change in frequency and change in the tie-line power. In this case to make the steady-state tie-line power zero (i.e. $\Delta P_{tie} = 0$), another integrator loop for each area must be introduced in addition to the integral frequency loop to integrate the incremental tie-line power signal and feed it back to the speed changer.

The requirements of the integral control action are:

- ACE must be equal to zero at least one time in all 10-minute periods.
- Average deviation of ACE from zero must be within specified limits based on percentage of system generation for all 10-minute periods.

Figure 4 shows the Block diagram of Conventional PI Controller on i-th area

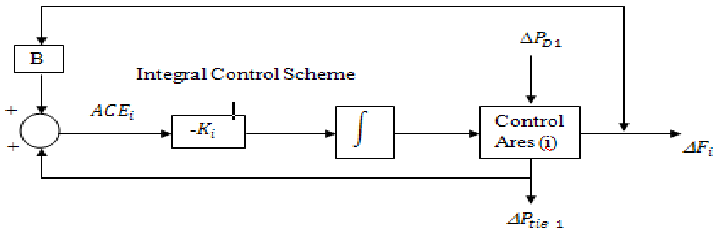

Figure 4: Conventional PI Controller on i-th Area

The control input $U_i$is constructed as follows:

$$U_i = -K_i \int_0^T ACE_i \; dt = -\int_0^T (\Delta P_{tie\ i} + B_i \Delta F_i)\, dt \tag{3}$$

Taking the derivative of the equation yields

$$U_i = -K_i(ACE_i) = -K_i(\Delta P_{tie\ i} + B_i \Delta F_i) \tag{4}$$

The constants $K_i(1, 2)$ are the gain of the integrator. It is observed that for decrease in both frequency and tie-line power generation should decrease, i.e., if the ACE is negative, the speed-changer position decreases and hence the power generation should decrease, i.e., if the ACE is negative, then the area should increase its generation, so negative is assigned to the right-hand side term.

ANFIS

Numerous advances have been made in developing intelligent systems, some are inspired by biological neural networks. Researchers from many engineering disciplines are designing Artificial Neural Networks (ANNs) to solve a variety of problems like Pattern Recognition, Optimization and Control Systems. Neural Networks provide an attempt to model the structure of the human brain and are based on self learning. The structure is highly reliable, resulting in the capability to self organize to represent the information and rapidly solve problems in real time. However Artificial Neural Networks are limited by the fact that they can only replicate a small fraction of the brain's total structure.

The ANFIS is a multi layer Adaptive neural network based fuzzy inference system. ANFIS algorithm is composed of fuzzy logic and neural network to implement different node functions and tune parameters of fuzzy inference system (FIS) structure using a hybrid learning mode.

The development of the control strategy to control the frequency deviation of the two area power system using the

concept of ANFIS control scheme is presented here. The Neuro fuzzy method mixes the advantages of neural networks and fuzzy theory to design a model that uses a fuzzy theory to represent knowledge in an interpretable manner and the learning ability of a neural network to optimize its parameters. The proposed controller uses fuzzy logic algorithm with a structure of artificial neural networks (ANN) in five layers in order to reap the benefits of both methods. ANFIS is a important approach in Neuro-fuzzy development which was introduced by Jang. The block diagram of the proposed ANFIS based load frequency control consists of four parts namely fuzzification, knowledge base, neural network and de-fuzzification blocks shown in Figure4

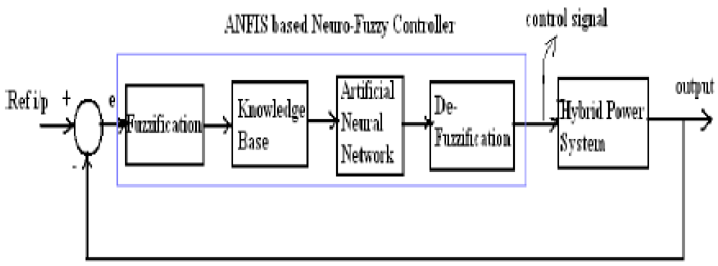

Figure 5: Block Diagram of ANFIS Based Load Frequency Control

The proposed Adaptive Neuro Fuzzy Inference System trains the parameters of the fuzzy logic controller. The required neural network structure is shown in Figure 5. In the fuzzy logic controller the error and its derivative are taken as the inputs and again these inputs are divided into five linguistic variables.

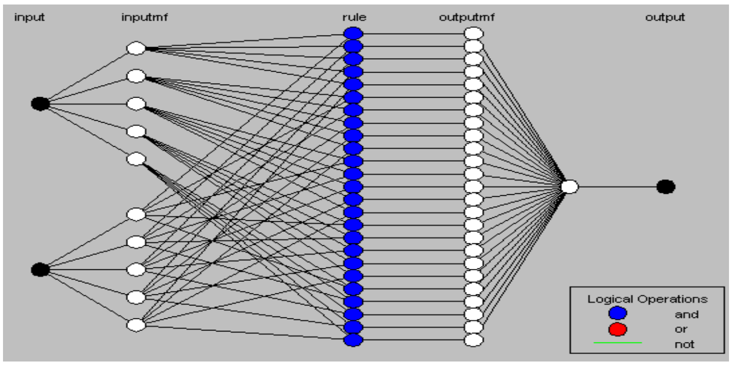

Figure 6: Neural Network Structure

The Membership functions for Fuzzy logic controller are shown in figure 6a & 6b.

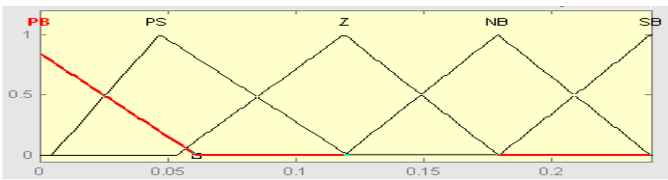

Figure 6a: Membership Function for Input (ACE)

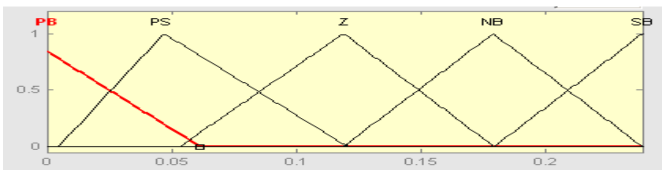

Figure 6b: Membership Function for Derivative of the Input

In this work we propose to use an adaptive network based inference system in order to generate fuzzy membership functions and control rules for the load frequency control. A proportional integral controller is used to provide

the required trained data. The controller design process consists of generating input-output data pairs to identify the control variables range and initial fuzzy membership functions, and then to tune or adapt them using an ANFIS network structure. The controller inputs are the ACE and rate of change of ACE and the output is the control signal.

Algorithm steps to design a ANFIS

- Draw the simulink model of the power system under consideration with PI controller and simulate with the given rule base.
- Collect the training data with PI controller included. The two inputs i.e. ACE, rate of change of ACE and the output signal of the controller represent the training data. The training data consists as much information as possible about the plant behavior for different load perturbations.
- Use “**anfisedit**” to create the **.fis** file.
- Load the training data, which is collected in step-2 and generate the **FIS structure** with suitable membership functions.
- Train the generated **FIS** with the collected data up to a certain number of epochs.

SIMULATION AND ANALYSIS

Simulations were performed using the proposed ANFIS Controller and the conventional PI Controller for the two area power system under consideration. All the performance indices such as settling time, overshoot and steady state error are minimized for different load disturbances. The system parameters are given in following Appendices.

Appendix: Numerical Values of the Two-Area Power System Model

The interconnected power system consists of two control areas. Two control areas are treated as identical.

Case Study 1	Case Study 2
T_g= 0.08 sec	T_g= 0.08 sec
R_1= 2.4 Hz/pu	R_1= 2.4 Hz/pu
R_2= 2.4 Hz/pu	R_2= 2.4 Hz/pu
T_P= 20 sec	T_P= 20 sec
T_t= 0.3 sec	T_t= 0.3 sec
b_1= 0.425 pu	b_1= 0.8 pu
b_2= 0.425 pu	b_2= 0.8 pu
T_{12}= 0.086 pu	T_{12}= 0.444221 pu
K_p = 120	K_p = 120
a_{12} = -1	a_{12} = -1

Simulation is carried out for a step load disturbances of 0.01pu and time t=0 sec with PI Controller. These responses of change in frequency for case study 1 are presented in Figure 7.

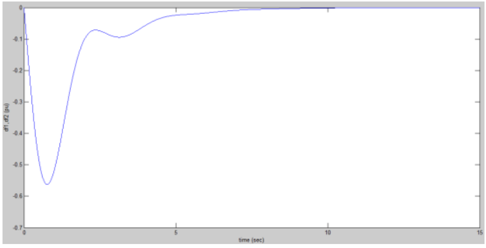

Figure 7: Frequency Deviation verses Time in Conventional PI Controller with Case Study1

The conventional PI Controller gives zero frequency deviation with settling time around 12 sec, peak overshoot about 0.5624 pu. It takes oscillations more time to settle down. Similarly the response of conventional PI controller with case study *2* is shown in figure 8.

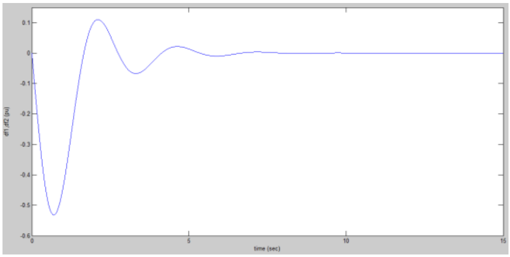

Figure 8: Frequency Deviation verses Time in Conventional PI Controller with Casestudy2

In this case the conventional controller gives more oscillations and settles down at 1*3* seconds with peak overshoot about -0.5*32* pu. Figure 9 shows the response of Adaptive Neuro Fuzzy Inference System based Load Frequency Control in Two area power system for the same 0.01pu load disturbance.

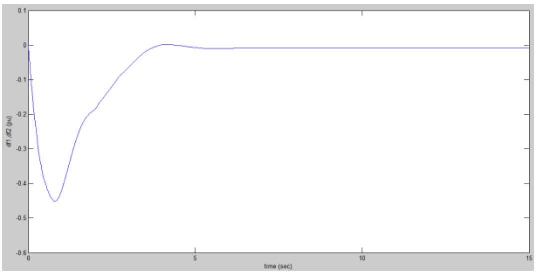

Figure 9: Frequency Deviation verses Time in ANFIS Based Controller with Case Study1

With the proposed controller, it is clearly observed from figure 10 that the system has a steady state frequency deviation of zero. In this case, settling time is around *8* seconds and peak overshoot is *-0.45* pu. Responses of change in frequencies for Case Study 2 are shown in Figure 10.

Figure 10 shows the response of the case study 2 as follows.

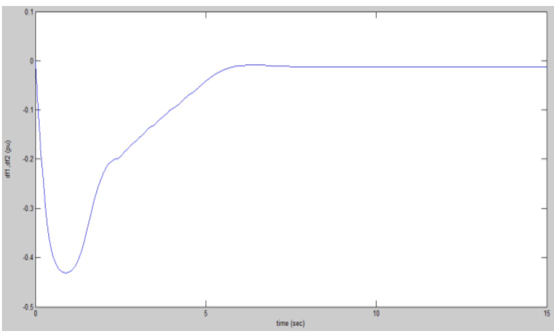

Figure 10: Frequency Deviation verses Time in ANFIS Based Controller with Case Study2

COMPARISON OF RESULTS

Table 1

S. No		Conventional PI-Controller	ANFIS Controller
Settling time in sec	Case study-1	0.01 pu load	0.01 pu load
		12	8
	Case study-2	13	8.5
Maximum Peak over shoot in pu	Case study-1	-0.5624	-0.43
	Case study-2	-0.532	-0.45

From the above comparison, it is clearly noticed that the Adaptive Neuro Fuzzy Inference System based Load frequency Controller gives best control action compared to conventional PI Controller. Following are the key observations made.

- Conventional PI Controller is simple for implementation but takes more time for the oscillations to settle down and gives large frequency deviation.
- The proposed Adaptive Neuro Fuzzy Inference controller can handle the nonlinearities quickly when compared to conventional PI Controller and brings steady state deviation in frequency to zero.

CONCLUSIONS

In this paper, the Adaptive Neuro Fuzzy Inference System based Load Frequency Control is proposed for a two area power system in each control area. The results have been compared with conventional PI controller. The results proved that the Adaptive Neuro Fuzzy Inference System based LFC gives better response as compared to conventional controller in terms of peak overshoot, settling time and steady sate error. Proposed ANFIS controller is not only simple to design but also easy to implement. Moreover, the ability to adapt to disturbances makes the proposed controller more effective. Also the learning ability of ANFIS architecture can be used to generate mature membership functions and fuzzy rules based on training data when the human export knowledge is not reliable.

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